King's College London

UNIVERSITY OF LONDON

This paper is part of an examination of the College counting towards the award of a degree. Examinations are governed by College Regulations under the authority of the Academic Board.

B.Sc. EXAMINATION

CP/144A Nuclear Physics

Summer 1998

Time allowed: THREE hours

Candidates must answer SIX parts of SECTION A,
And TWO questions from SECTION B.

The approximate mark for each question is indicated in square brackets.

Separate answer books must be used for each section of the paper.

You must not use your own calculator for this paper.
Where necessary, a College Calculator will have been supplied.

TURN OVER WHEN INSTRUCTED

Atomic mass unit	m_u	=	1.660×10^{-27} kg
Avogadro's constant	N_A	=	6.022×10^{23} mol^{-1}
Elementary charge	e	=	1.602×10^{-19} C
Speed of light	c	=	2.998×10^{8} ms^{-1}
Rest mass of an electron	m_e	=	9.019×10^{-31} kg

SECTION A – Answer any SIX parts from this section.

1.1) The half life of ^{226}Ra is 1602 years. Calculate the decay constant and the activity of 1g of radium.
You may assume that the decay constant $\lambda = \ln(2) / t_{1/2}$ and that the activity A is given by $A = \lambda N$ where N is the total number of radioactive atoms

[7marks]

1.2) Show that on the basis of the liquid drop model of the nucleus the radius R of a nucleus is given by

$$R = R_0 A^{1/3}$$

where A is the atomic mass number and R_0 is a constant.

[7 marks]

1.3) The $^{35}Cl^{+}$ and $^{37}Cl^{+}$ isotope ions are separated in a 180^{o} mass-spectrograph. If a magnetic field flux density of 0.1 T is used and the ions have velocities of 5×10^{4} ms^{-1} calculate the separation of the lines produced by these isotopes.

[7 marks]

1.4) The Q value for the α decay process $^{233}U \rightarrow {}^{229}Th + \alpha$ is 4.909 MeV. When ^{229}Th is formed in the excited state $^{229}Th^{*}$ the emitted α particles are found to have an energy of 4.729 MeV. Calculate the energy of the γ-ray emitted in the process $^{229}Th^{*} \rightarrow {}^{229}Th$.

[7 marks]

1.5) In a fission based reactor explain the importance of a) control rods and b) delayed neutrons.

[7 marks]

1.6) A cyclotron with a radius of 75 cm and a magnetic field of flux density 1.4 T is used to accelerate $^{7}Li^{3+}$ ions. Calculate the frequency of the accelerating voltage required.

[7 marks]

1.7) For light stable nuclei the number of neutrons N is normally equal to the number of protons Z while for heavy stable nuclei N>Z. Show how this can be explained on the basis of the shell model of the nucleus.

[7 marks]

1.8) Sketch the form of the pulse height spectrum that you would expect to observe when a scintillation counter is used to detect 0.6 MeV γ-rays, labelling important features.

In the Compton scattering process a γ-ray with initial energy E_γ scattered through angle θ has final energy $E_\gamma^{/}$ where

$$E_\gamma^{/} = E_\gamma\ E_0 \,/\, (E_0 + E_\gamma(1 - \cos\theta)).$$

Here E_0 is the rest mass energy of an electron (0.51 MeV). Use this expression to find the energy of the Compton electrons giving rise to the Compton edge in your spectrum.

[7 marks]

SECTION B – Answer TWO questions.

2) For α particle decay it is observed that small changes in the kinetic energy of the α particle correlate with large changes in the half life of the nucleus. Describe how the process of quantum mechanical tunnelling accounts for this.

[15marks]

For the following decay processes

$$1)\quad {}^{238}U \rightarrow {}^{234}Th + \alpha$$
$$2)\quad {}^{23}Ne \rightarrow {}^{23}Na + e^{-} + \bar{\nu}$$

calculate the Q value for the reaction and comment on the kinetic energy of the α or β particle produced.

The following atomic masses are in $m_{u,}$ ${}^{238}U$, 238.05079 , ${}^{234}Th$, 234.04363, ${}^{4}He$, 4.00260, ${}^{23}Ne$, 22.99446, ${}^{23}Na$, 22.98977.

[15 marks]

3) The semi-empirical expression for the binding energy *B* (in MeV) of odd A nuclei, based largely on the liquid drop model may be written

$$B = 15.84\,A - 18.33\,A^{2/3} - 0.71Z^2/A^{1/3} - 23.2(A - 2Z)^2/A$$

Explain the origin of each term in this expression.

[20 marks]

Use binding energy to explain why for heavy nuclei the fission process can be used as a source of energy while for light nuclei the fusion reaction can be used.

[10 marks]

4) Describe with the aid of a suitable diagram the operation of a drift tube linear accelerator. Show that at non-relativistic energies the length of the drift tube is proportional to $n^{1/2}$ where n is the number of the accelerating stages.

[15 marks]

Electrons are injected into a linear accelerator and accelerated to 30 GeV. The accelerating voltage is applied with a frequency of 200 MHz. Calculate the length of drift tube required for a 1000 eV electron and for a 20 GeV electron.

[10 marks]

What advantages does a linear accelerator have over a "circular" accelerator for the acceleration of electrons.

[5 marks]

5) Explain how combinations of the three quarks listed below has enabled the meson and baryon particle families to be rationalized.
Use the quark properties given in the table below to draw eightfold way diagrams for spin zero mesons and spin 1/2 baryons and predict their charge, strangeness and isospin.

[30 marks]

	Charge Q	Isospin T_3	Strangeness S
Up	+2/3	+1/2	0
Down	–1/3	–1/2	0
Strange	–1/3	0	-1